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# THE OVERALL SPECTRUM OF ASTRONOMICAL RESEARCH POSSIBILITIES UTILIZING MANNED EARTH-ORBITAL SPACECRAFT

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The possibilities for manned earth orbital astronomy are discussed in three parts. The Mercury, Gemini, and first phases of the Apollo programs provide small individual experiment capability which is briefly reviewed. The later stages of the Apollo program, 1968-1972, provide greatly increased capability in conjunction with initial development of orbiting research laboratories. Several major astronomical missions are possible including high resolution solar and stellar investigations. These missions should play an important role in planning for a large manned orbital telescope, in the 100 or more inch size range. This last program is generally agreed to represent one of the ultimate goals of space astronomy.

## INTRODUCTION

Astronomical observations from manned spacecraft have been quite limited to date, but the opportunity to conduct experiments on manned vehicles is broadening. The experimental program began with the X-15 airplane, continued in a limited fashion on the Mercury spacecraft, and is expected to achieve a broader base on the up-coming Gemini and Apollo Earth Orbital flights. The Gemini science program will be

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carried on ten manned flights which will start this spring and continue through 1967. The program will then utilize the greater payload capacity and longer observing periods afforded by the Apollo Earth Orbital missions.

Since the primary objective of the Mercury program was to prove that man could travel safely in a spacecraft, and that he could play a substantial role in controlling that spacecraft, it followed that a minimum of time and space could be devoted to any purely scientific experiments. Nonetheless a few scientists began to formulate simple experiments or tasks that could be accomplished within the space, weight, and time constraints of the Mercury program, and began to try to interest the astronauts in carrying out these observations. Some of the same experimentors, as well as new ones, have now been able to sophisticate the original experiments, or plan different ones, for the Gemini and Apollo Earth Orbital programs. For all flights the experimental programs are interdisciplinary, that is, they will include timely and feasible experiments drawn from various fields, including biosciences, meteorology, space physics, geosciences, and astronomy.

#### MERCURY PROGRAM

Very early in the Mercury program the astronauts began to comment on the splendid view from space and particularly on the beautiful sunsets. Using a 35mm camera and color film both Astronauts Glenn and Carpenter took sunset photographs. (Figure 1) On the basis of these photographs, W. Cameron, et. al., (1963) comments that "the flattening effect of refraction on a setting celestial object as seen above the atmosphere...has been demonstrated by direct (visual and photographic) observations on the MA-6 and MA-7 flights." The lack of **precise** times for the astronaut photographs preclude an exact comparison of theory and observation, but a reasonable simulation of the observational data was achieved by computation from refraction theory.

In early December, 1961, prior to John Glenn's MA-6 flight, it

was suggested that an observer in a space capsule might see the airglow layer above the earth. Since the green oxygen line at 5577 was known to be an important constituent of the airglow, it was suggested that a narrow pass band filter centered on this wavelength might improve the astronaut's view of the airglow layer. A 10Å band width filter was quickly fabricated and made ready for Glenn's flight. No satisfactory observations could be made with it, however, since Glenn found that he was not sufficiently dark-adapted (Glenn, 1962). Three months later the filter was again carried on MA-7. Carpenter did manage to become sufficiently dark-adapted to observe with the green filter as well as to make naked-eye estimates of the airglow. Later comparing Carpenter's measurements with their own rocket observations, a group of Naval Research scientists found remarkable agreement in the measurements of dip angle and luminance (Kooman, et. al., 1963). During the last Mercury flight, MA-9 (May 15-16, 1963), Cooper obtained a series of color photographs for the University of Minnesota dim sky photography experiment. An f/1, wide angle robot camera was used in order to obtain measurements of brightness and geometry of the airglow. Nine exposures ranging from ten seconds to two minutes were used to determine the height and width of the airglow, giving a height between 77 and 111 kilometers, and a width of  $24 \pm 3$  kilometers. In addition, color densitometry was performed on the two-minute exposure (Figure 2) and the results supported earlier work by the NRL group (Kooman, et. al., 1963) that the green color of the airglow arises more from the continuum than the 5577 line, in a ratio of 4 to 1. This differed from Carpenter's visual observations that the airglow seen with the narrow-band filter had the same intensity as seen with the naked eye (Gillett, Huch, Ney, 1964).

#### GEMINI PROGRAM

More dim sky photography is planned by the University of Minnesota for the Gemini flights with two objectives in mind: 1) to obtain more data on the airglow to explain variations in the height of the layer--whether latitude, time, or geographical position, and

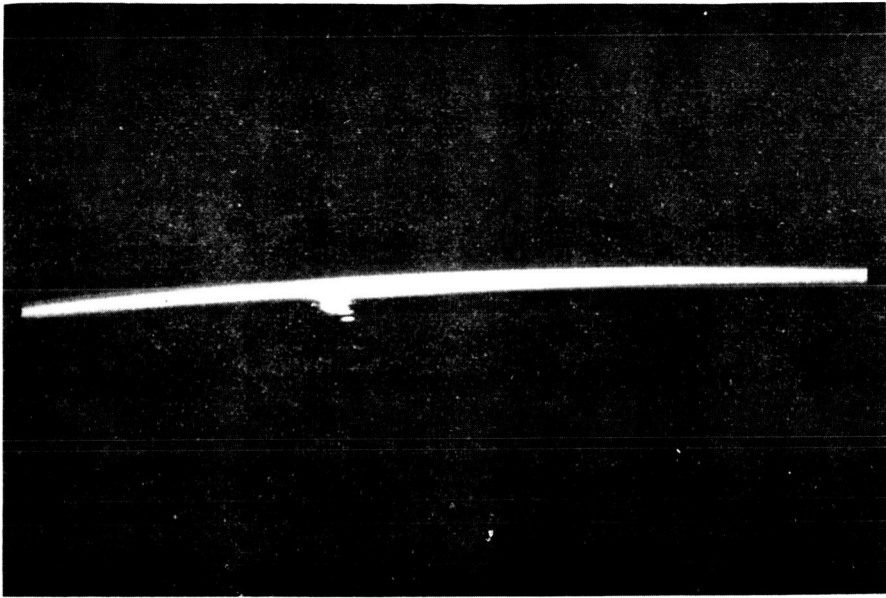


Fig. 1 A view of the horizon photographed by Astronaut M. Scott Carpenter while in orbit. The sun is just below the horizon.



Fig. 2 Blue earth and green airglow layer (smeared by capsule motion) photographed by Astronaut Gordon Cooper from MA-9 for the University of Minnesota dim light photography experiment.

2) to obtain photographs of the Zodiacal light near the sun. For Gemini, Kooman of NRL has also planned airglow horizon photography which will use high speed black and white film. The manned earth-orbital flights are well suited to airglow studies. To date experiments have been limited to the visual, but it is hoped to extend them to the ultraviolet on Apollo missions.

Color synoptic terrain and weather photography obtained during Mercury on an opportunity basis will be continued on Gemini and Apollo Earth Orbital flights. Principally these studies have been of interest to geologists and meteorologists for comparison with the coarser pictures obtained from unmanned systems. But increasingly our understanding of what can be photographed, or otherwise detected, from space concerning the nature of the earth's surface will have profound implications for later analysis of the features of other planets. (Lowman, in another paper at this symposium, has discussed general applications of high altitude earth photography.)

In a number of ways the Gemini series of flights will offer a better opportunity than Mercury for scientific experimentation. For instance, optical quality windows will be used on Gemini whereas Mercury had a multi-layered Vycor window which resulted in rather poor visibility. In addition, limited extra-vehicular activity by the astronauts will make possible the performance of a few experiments outside the vehicle, including retrieval of a micro-meteorite collector and nuclear emulsions prior to re-entry.

Of particular interest to astronomers is the opportunity afforded by spaceflight to extend the region of the spectrum available for celestial studies of the stars, the sun, the planets, and the interplanetary and interstellar medium. From the ground the observable spectrum terminates at  $3000\text{\AA}$  at the high energy end. From balloons and rockets exploration at shorter wave lengths has begun and there is expectation that both manned (Gemini and Apollo Earth Orbital) and unmanned (Orbiting Astronomical Observatory) orbital mission will soon gather both synoptic and specific ultraviolet stel'

for comparison with theoretical models. Also of great interest, and importance to the space program, is observation of the UV spectrum of the moon and planets. Use of a simple fast UV camera on Gemini will lead toward development of a Schmidt camera for Apollo to obtain moderate dispersion spectra giving some detailed information on prominent ultraviolet features in the spectra of hot stars.

#### APOLLO EARTH ORBITAL PROGRAM

Unlike Gemini, extra-vehicular activity is not planned for Apollo Earth Orbital flights. In order to obtain access to the outside for scientific purposes an airlock located in a hatch in the command module is being designed. Interchangeable experiments placed in canisters built to fit the airlock will operate with power and telemetry connections through the interface. The experiments to be accomplished on early Apollo E-O flights will include stellar ultraviolet spectroscopy with a Schmidt camera, and x-ray astronomy with a pinhole camera. These experiments, and others, will employ the airlock.

Later flights in the Apollo E-O program are expected to continue ultraviolet photographic studies, to pursue x-ray astronomy with a telescope, and to begin astronomical survey photography with a fast telescopic camera having ultraviolet reflecting optics and equipped with its own inertial guidance system for fine pointing. This relatively large instrument will probably be located near the exit port of the lunar excursion module since it will be too large for the airlock system. Although less convenient for access by the astronaut this latter mode is considered feasible and it makes it possible to plan for larger systems than the airlock can accommodate. Other experiments of astronomical interest to fill out the Apollo E-O program will include micrometeorite collection and observation of heavy particle radiations as they appear most feasible and timely. Solar studies including coronagraphic and far UV experiments are being contemplated, but are still in the study phase. Throughout the manned

experimental program careful attention will be directed toward use of man in the loop to adjust equipment, alter programs, select targets, and generally insure success of the experiments.

#### AES PROGRAM

No formal decision has been made at the time of this writing as to what direction the national space effort will take beyond Apollo. Maximum effort could be concentrated into any one or a combination of three areas; 1) Extended programs in earth orbit leading toward an orbital space station, 2) Extended lunar surface exploration and exploitation leading toward a permanent base, or 3) Extended planetary exploration, especially of Mars. In any earth orbital, lunar orbital, or initial lunar surface operations the Apollo spacecraft has very broad potential applicability which goes well beyond its primary mission of a quick round trip to the lunar surface. In particular, in earth orbit the vehicle is the logical first stage in development of an orbital laboratory, and NASA is making extensive studies in this area. The total picture of Apollo applicability in earth orbit, lunar orbit, and initial lunar surface operations is presently referred to as the Apollo Experimental Support Program or AES, and is associated with the 1968-1972 time period.

The Apollo E-0 program represents the developmental phase of the Apollo spacecraft in earth orbit. During this phase preparation for the lunar mission is primary and any scientific experimentation must in no way deter from this. Weight, space, and time for experiments is very limited. Once the Apollo vehicle is proven out in orbit, however, the picture changes very greatly. Scientific programs become one of the primary reasons for extended orbital missions, and maximum effort can be expected to modify and adapt the Apollo vehicle for such purposes. No major change is probable in the command module; some AES experiments will continue to be carried in the command module very much as in Apollo E-0. The service module may be modified by relocation of components to free one

longitudinal sector and provide an appreciable volume for housing of experiments. The most exciting possibilities, however, involve utilization or replacement of the lunar excursion module which is obviously not necessary in purely orbital operations. The simplest modification utilizes the LEM ascent stage as a laboratory and removes the descent stage to permit scientific payload instead. For optimum capability the LEM is replaced by a special laboratory structure. Several thousand pounds of scientific payload can be orbited by the Saturn Ib. The Saturn V can orbit in excess of 100,000 pounds.

The primary environmental factors which astronomical space missions are able to exploit to advantage are three in number. First, atmospheric extinction is essentially eliminated which opens up spectral regions inaccessible through the atmosphere. This is especially important in the ultraviolet, x-ray, and  $\gamma$ -ray portions of the spectrum. Exploration in the ultraviolet is the prime objective of all the initial major OAO experiments, and will be a very important part of any manned program. One possible application of the AES vehicles involves carrying into orbit an OAO type of instrument package, initializing it and perhaps using it directly for a while, then setting it free in unmanned operation. Occasional servicing and change of film or other packages would be possible by redocking. Continuous real time operation would also be possible. A mission aimed specifically at x-ray and  $\gamma$ -ray studies is a good possibility within the AES program. Maintenance and initial instrumental assembly would be important roles for man. For infrared studies outside the atmosphere blanketing, manned systems are very attractive, and important IR work will no doubt be included in the AES program. Only on a manned system can one hope to effectively manipulate the cryogenic fluids required for operation of IR detectors. Some radio astronomy is possible in low earth orbit, but it does not have major advantages. The orbit is still within the ionosphere and is subject to uncontrolled radiation of all types arising from the earth. Major astronomy ventures

would not seem too likely in the AES program.

The second major advantage in the space environment is the elimination of image degradation by the atmosphere. Exploitation of this high resolution capability has two important aspects. The first relates to extended surfaces, and the second to unresolved point sources. High resolution solar studies are a prime example of the former and will no doubt provide one or more major AES missions. Both high resolution heliograph and coronagraph instrumentation will be required to study detail on the surface, limb, and into the corona. Some radio equipment would probably be desirable on a solar mission. Two solar experiments to test relativistic theory would be appropriate to an AES solar mission. These are the measurement of deflection of light in the solar gravitational field, and calibration of the solar ellipticity to high precision to correct the determination of the advance in the perihelion of Mercury. A sun-synchronous near-polar orbit would give a solar oriented mission its maximum effectiveness, although a Saturn V would be required to achieve this orbit.

The AES program has the capability of placing in orbit a long focus reflecting telescope of appreciable aperture, 40 to 60 inches, for general non-solar high resolution studies. A 60 inch diffraction-limited telescope can resolve detail to the Rayleigh limit of 0.07 arc seconds at 4000Å. This is a full order of magnitude greater than normally possible working through the atmosphere. The application to detailed studies of planetary surfaces is obvious. In order to effectively utilize the high resolution potential of a space telescope it must have a rather long effective focal length to match the resolving power of the telescope and receiver. The optical configuration appropriate to give a long effective focal length while retaining a compact mechanical design is the Cassegrain type. The field of view is quite restricted, so for wide field survey work a separate telescope or an alternative optical configuration is required.

A very few nearby giant stars may produce a slight enlargement of the Airy diffraction disc. With this exception the stars are point sources. From within the atmosphere stellar image size is determined by seeing and is rarely less than about one arc second. (See Figure 3). The space telescope therefore concentrates the collected photons in roughly  $1/100$  the angular area. The signal to noise (sky background) ratio in the area of the star image is raised by 100 which means we can in principle detect stars a full five magnitudes fainter than from the earth with the same instrument. Because of the finite resolving power of photographic films this gain is not simple to achieve, but it can be achieved if sufficient time is allowed. A 60-inch telescope can therefore work in principle to roughly magnitude 26 or 27. The implications in terms of studies of stellar populations in external galaxies, calibration of the cosmological distance scale, and many other problems are obvious. The greatly increased resolving power in space instruments also opens vast opportunities for detailed studies in very crowded fields such as in compact clusters, the galactic nucleus, and external galaxies where the images simply merge together when seen from the earth's surface. Multiple star systems of very small separation can also be studied very effectively.

The third primary space environment advantage for astronomy is reduction of the sky brightness by working above the airglow. Even more significant is the great increase in the stability of the sky brightness at any point. The general brightness reduction (roughly a factor of 2) will permit wide field photography to a fainter surface brightness which will be important in morphological study of galaxies and nebulae. The stability is fundamental to increasing the precision of measurement in photoelectric detection. Combination of high resolution with sky brightness reduction and stability will permit wide-band photometry to faint limits well beyond anything possible from earth. For bright stars luminosity instabilities of tenths or hundredths of a percent can be detected whereas from earth no effects below one percent can be trusted.

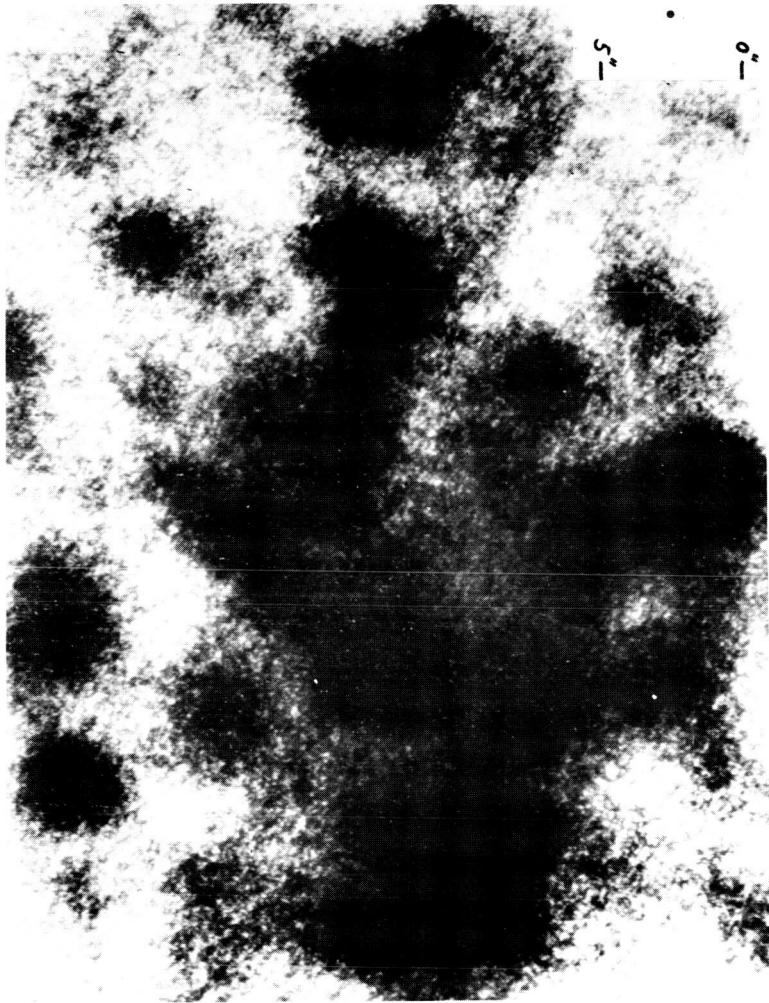


Fig. 3 A very much enlarged picture of the center of a star cluster in the Small Magellanic Cloud obtained with the 74-inch Mount Stromlo Observatory telescope (Canberra, Australia) operating in a 45-inch F/8 configuration. The natural diffraction image for such a telescope is shown by the spot at the upper left. Atmospheric degradation of the images produces the observed 2-3 arc second images.

The primary limiting factors for a high resolution space telescope will be control of thermal distortions and control of light scattering. To achieve the ultimate in faint work and resolution these factors must be precisely controlled. It seems doubtful that sufficient control will be possible to permit a telescope to reach its ultimate limits, but a great increase over earth capability can come from nearly any system. Some of the ultimate capability experiments with high resolution telescopes may have to await development of a lunar base operation.

The type of men selected to operate AES instrumentation in space will greatly influence the effectiveness of scientific programming. The present NASA astronaut-scientist program gives reason to believe that highly qualified scientists will be utilized in the AES program to maximize the return.

The AES program can serve several very basic purposes in laying groundwork for longer range programs (such as the large manned orbital telescope (MOT) and lunar base programs) as well as producing fundamental advances in terms of direct scientific data returns. The program can determine in depth the most effective ways to utilize man, develop the most effective techniques for data collection and analysis, and explore the types of programs most significant for space operations. It would be difficult to underestimate the importance of the AES program.

#### LARGE MANNED ORBITAL TELESCOPES

With the eventual establishment of large manned stations in space having greatly extended lifetime the whole complexion of scientific programs in space will change. The inclusion of Astronaut-Technicians and Astronaut-Scientists in the crew of such stations will permit in situ participation in the scientific program with all the advantages of rapid modification and reprogramming of experiments and observations.

Clearly, this capability will revolutionize observational astronomy outside the atmosphere; the establishment of a large as-

tronomical telescope as part of a manned observatory in orbit about the Earth would have unique capabilities not attainable by ground-based equipment nor by unmanned orbiting observatories such as OAO. Indeed for the first time it would be possible to combine much of the operational flexibility of large ground based telescopes, such as the 200" Mt. Palomar Telescope, with the seeing conditions enjoyed by space telescopes such as Stratoscope and OAO.

With the improvements in resolution, collecting power and wavelength range that attend such a system the whole subject of observational astronomy is given new dimensions. Lyman Spitzer, Jr. (1962) and others have discussed previously the many new observations that could be made and the possible impact of these observations on our understanding of the universe. The telescope must be capable of making Planetary, Stellar and Extragalactic observations using photographic, photometric, and spectroscopic techniques and these requirements will determine, to a large extent, the telescope design.

Moreover, in order to exploit the capabilities of a large orbital telescope, the system must be designed to operate near the diffraction limit, it must be capable of variable focal length, and it must observe over as much of the spectrum as possible. These requirements place great demands on the technology especially in the areas of large optics, pointing and control, and thermal control; moreover considering the need for versatility and the capability of varying the optical configuration to cater to various kinds of observational programs, it is clear that human participation is required in the operation of the system.

Thus the following important questions arise when the feasibility of the large manned orbital telescope is considered. Firstly, what technological advances are necessary to support such a system?: secondly, what is the useful role of man in the operation of the system? In recent months studies of a 120" aperture Manned Orbital Telescope (Langley Research Center Study, 1964-1965) have been initiated by NASA to answer these questions and it is expected that

a much clearer picture of the real design problems will emerge by the end of this year (1965). For the present, they can be discussed only in the broadest terms.

Figure 4 shows a conceptual design of the large telescope under study. It is a Cassegrain system of short focal length characterized by a large reflecting optics in conjunction with sub-diameter replaceable transmission optics. Sensing equipment is placed behind the primary mirror and is accessible to the occupant of the telescope cabin. The whole system is shown in the figure in a docked position allowing passage of men and equipment to the telescope cabin from the station. A space station having extended lifetime with resupply capability is envisioned (see for example Langley Research Center Study, 1964).

#### Technological Problems

Looking first at the technological problems, perhaps the most formidable is that of fabricating and maintaining the large primary mirror to the required tolerances, that is, to approximately  $1/10$  of the wavelength of the light to be received.

The choice of materials for the mirror is particularly important since this determines its dimensional stability: significant thermal distortions can result from very small amounts of extraneous heating and both high thermal conductivity and low thermal expansion are required. The condition that negligible distortion takes place is written:

$$\frac{q \alpha t^2}{k \lambda} \ll 1 \quad (1)$$

(where  $q$  is the extraneous heating rate/unit area  $\alpha$  the thermal expansion coefficient,  $t$  the mirror thickness,  $k$  the thermal conductivity).

Metal mirrors such as beryllium or aluminum have been considered in view of their high thermal conductivity. Recently, however, progress has been made in producing glass having the property of

essentially zero thermal expansion over a wide temperature range with the result that glass (and quartz) must be retained as possible candidates.

It is seen from the form of the thermal distortion parameter that the mirror thickness should be made as small as possible. In this regard the fact that the mirror is to be used in orbit (i.e., in a weightless condition) alleviates the structural design problem and allows the mirror thickness to be appreciably less than that for a ground based telescope of comparable size. Such a thin mirror would require a carefully designed support system for use during fabrication, transportation and launch.

The other important question that arises in the mirror design relates to its focal length: from the point of view of requiring a compact overall configuration for ease of launch a short focal length is desirable - say  $F/2$ , but the difficulties in forming the mirror blank tends to increase with decreasing focal length. The alternative would be to use a configuration of longer focal length - say  $F/4$  - but in this case the overall configuration becomes too long to be launched easily and would require a collapsible structure. This latter arrangement, however, would compound the problem of keeping the secondary mirror in proper alignment.

When the telescope is in an operating condition in orbit it must be pointed within angular tolerances less than the telescope angular resolution to take advantage of the diffraction limited design (.03 secs arc for a 120" telescope) and the fine attitude control system must point the system within .01 secs arc.

This requirement raises the question of how to sense an angular error whose magnitude is less than the resolving capability of the telescope. One possibility under consideration is to use the telescope itself to supply the guidance sensors with light from the viewed object on an intermittent basis. Even here, it would be necessary to split the Airy disc image (for a point source) and balance the intensity of the halves in order to resolve an angular dimension less than the diffraction limit.

A further possible source of difficulty presents itself when the dynamical interaction between the attitude control system and the mirror and telescope structure is considered. Clearly care must be taken in the design to ensure that the natural frequencies of the structure are sufficiently different from the control cycle frequencies that resonance is eliminated.

The fabrication of a 120" aperture diffraction limited telescope with appropriate pointing control is not completely within the state of the art at the present time. However, a 120" telescope is larger, only by a factor of 3, than existing diffraction limited space telescopes (i.e., Stratoscope and OAO) and work on larger mirrors, such as the 150" diameter mirror recently acquired by Kitt Peak Observatory, is already in progress. With the proper emphasis on the more significant problems it should be possible to extend the technology so that telescopes as large as 120" to 150" aperture will be attainable within the next few years.

#### Operational Problems and Role of Man

The whole question of the mode of operation of a large telescope in space is one that requires a great deal of thought. In particular the functions of the Astronaut-Technician and the Astronaut-Scientist in making the telescope more reliable and more versatile must be defined in such a way that the performance of the telescope is not compromised in any way by their presence. The role that man plays in the system will affect design philosophy and has to be taken into account from the very first. The present generation of unmanned systems are generally characterized by the requirement for extremely high reliability and this is achieved in part by sufficient redundancy to allow for component failure. Such redundancy, for large versatile systems will result in additional complexity, however, and this in turn reduces the overall reliability.

With the inclusion of a man in the system, capable of performing adjustment, maintenance and repair functions the system can be made less redundant and much less complex. There remain many

operations that are best automated, of course, and one of the first needs is to determine the most appropriate disposition of work functions between man and the automatic equipment.

Many of the functions that man can best perform are readily enumerated: one of the most important is that of re-aligning the optical system after the telescope is placed in orbit, and after each modification of the optical system. During observational periods the Astronaut-Scientist would be used to advantage in monitoring the results and if necessary changing the observational program to obtain additional measurements as required. The recovery and return to Earth of photographic plates and film is also most easily carried out by the Astronaut.

The ease with which these functions can be performed depends in large measure on the manner in which the telescope is associated with the space station. Three basic modes of operation (and variation within these modes) are presently under study, and are illustrated in figure 5.

In the 'attached' mode a soft docking of the telescope with the space station is made and thereafter the two remain permanently mated. Here the telescope is readily accessible to the station crew who can pass into the telescope cabin through an airlock: however, in order to point the telescope with the required accuracy, activity within the station would be severely restricted and the indications are that even the disturbance caused by a man raising his arm could affect significantly the fine attitude control.

In the other extreme, the 'separate' mode allows the telescope and the station to be operated independently at all times, with the advantage of no effect of station disturbances on telescope performance. In this mode the disadvantage arises from the requirement that the station crew leave the station and perform all telescope-related functions in space suits. A possible compromise mode - a 'dockable mode' - is that in which the station and telescope are operated separately during periods of observation but are docked in such a way as to allow easy access for periods of maintenance,

# TELESCOPE-TYPICAL CONFIGURATION

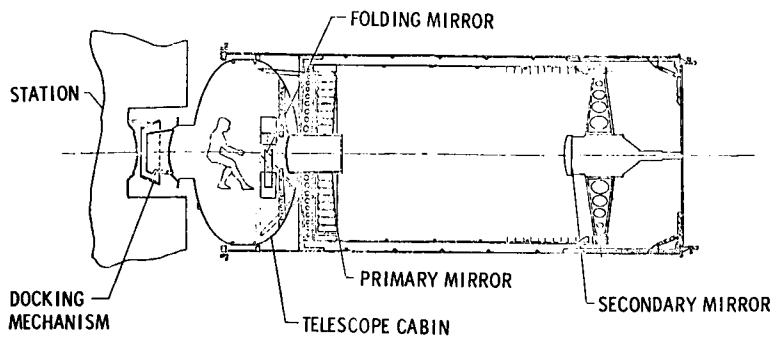


Fig. 4 A typical telescope configuration under consideration for a large manned orbital telescope (MOT).

# MOT OPERATIONAL MODES

(a) ATTACHED	(b) DOCKABLE	(c) SEPARATED
✓ ACCESSIBLE	POSSIBLE COMPROMISE	✓ INDEPENDENT OPERATION
✗ POSSIBLE CONTROL PROBLEM		✗ CONSIDERABLE SPACE-SUIT WORK

Fig. 5 Alternative modes of operation for a manned orbital telescope.

program modification, film recovery, etc.

Additional alternate modes that fall between the extremes illustrated here are also being considered (for example, loosely gimballed and tethered modes) and the advantages and disadvantages of each are being considered in arriving at preferred modes.

It is clear that the design and the mode of operation cannot be considered independently since the particular functions which the man is to perform in the system will influence the design (for example, the accessibility of sub-systems and components becomes much more important than for an unmanned telescope).

It would be premature to say that a system such as the one described here can be developed today but it is not too soon to promote the required technology and to plan for such observations in the near future. The contribution of this undertaking, both to science and technology, would more than justify the effort.

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